ADVANCES IN MEASURING TECHNIQUES FOR
TURBINE COOLING TEST RIGS - STATUS REPORT

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ABSTRACT

Instrumentation development at the Lewis Research Center pertaining to turbine cooling research has resulted in the design and testing of several new systems for obtaining surface temperature and pressure measurements. Surface temperature distribution measurements for turbine vanes and blades were obtained by measuring the infra-red energy emitted by the airfoil. The IR distribution can be related to temperature distribution by suitable calibration methods and the data presented in the form of isotherm maps. IR photographic and real time electro-optical methods are being investigated. The methods can be adapted to rotating as well as stationary targets, and both methods can utilize computer processing. Some areas under investigations are: optical transfer systems, calibration techniques, rapid data analysis.

Pressure measurements on rotating components are being made with a rotating system incorporating 10 miniature transducers. A mercury wetted slip ring assembly was used to supply excitation power and as a signal transfer device. The system has been successfully tested up to speeds of 9000 rpm and is now being adapted to measure rotating blade airflow quantities in a spin rig and a research engine. A 72-channel micro-electronic shaft data system has been developed to replace slip ring assemblies. A two-winding rotary transformer transfers data signals in a digital serial train to a bargraph display and printer. An advanced system development combining pressure transducer and thermocouple signals is underway.

This "Status Report" is intended to briefly describe each system, along with some applications. It is also intended to discuss the areas of interest that require further development.

INTRODUCTION

Instrumentation development in support of turbine cooling programs at the Lewis Research Center has resulted in the design and testing of several new systems for obtaining surface temperature and pressure measurements. These systems are: (1) Surface temperature mapping with infra-red techniques, (2) A 10-channel rotating pressure measurement system, and (3) A 72-channel micro-electronic Shaft Data System for transferring thermocouple signals from a rotating shaft.

Such systems are useful in experimental test facilities for investigating the performance of cooled turbine vanes and blades. Surface temperature and airfoil pressure distributions are required to study cooling scheme effectiveness, thermal stresses, blade life potential, and the heat transfer process.

The application of radiation techniques for making temperature measurements is growing rapidly. The accuracy of radiation pyrometer standards are improving steadily. Recently a council on Optical Radiation Measurements was organized as an outgrowth of an industry-government conference on national needs in radiometry and photometry. There are many standard radiation thermometer and thermal scanners commercially available today. I.R. detectors are improving constantly. Electro-optics is developing into a major technology. Much of this was due to military application in low light level (night vision) and NASA satellite systems developed for scientific missions such as the recent Earth Resources Program. These advances can be applied to turbine technology for surface temperature mapping of vanes and blades contained within gas streams produced by the burning of hydrocarbon fuels.

Imaging systems, like IR photography, that measure temperature distribution over an area without making contact with the surface are of utmost importance when heat-transfer processes are being studied. On cooled turbine vanes, the presence of thermocouples may interfere with the heat transfer process being investigated. Thermocouples may interfere by upsetting boundary layers, obstructing narrow cooling passages or altering the conduction heat transfer paths within the vane walls. Frequently the presence of a thermocouple may also be impractical from the standpoint of structural consideration.

Rotating pressure measuring systems are required for the measurement of the static pressure distribution on the surface of rotating airfoils, and for the measurement of the total and static pressures of a coolant flowing within rotating turbine blades. The former application could provide data for more accurate turbine (and compressor) design calculations and better estimates of external turbine blade heat transfer coefficients. The latter application could be used to measure coolant flow within air cooled turbine blades.

The transfer of thermocouple signals from a rotating shaft to a stationary location has usually been done with a slip ring assembly. These assemblies are troublesome and require frequent maintenance. In addition, their physical size increases with the number of data channels required. The shaft data system is capable of handling a large number of thermocouple data channels without the need for a large number of separate rings. It accomplishes this by switching data channels, one at a time, through a circuit that electronically processes them for removal from the shaft in the form of a digital serial train of information. In this paper each of the systems will be briefly described. Their applications will be presented and the future effort on these areas will be discussed.

I.R. SURFACE TEMPERATURE MEASUREMENT

I.R. systems are used to measure temperature remotely without contact. This is done by optically collecting and measuring the intensity of a narrow bandwidth of I.R. radiation emitted by a hot surface.

For the most part, the Lewis Research Center has concentrated on an I.R. photographic imaging technique for stationary vanes (ref. 1). The advantage of a thermal photograph is that it captures the temperature distribution of a scene in an instant of time for later screening and detailed surface temperature mapping. The technique is straight-forward. A thermal image is formed on film and then temperature distribution is determined from film density distribution. A thermal image for a particular camera exposure can cover an average span of about 200 K (400° F) in the temperature range between 800 K (1000° F) and 1400 K (2000° F). In addition, the photographic image can be resolved into very small spot sizes.

Surfaces emit radiation as a function of their absolute temperature. An indication of the typical energy variation with wavelength for several blackbody (or greybody) temperatures is shown in figure 1. The shaded region indicates the wavelength interval of concern. The detected radiation was restricted to a narrow wavelength interval (spectral bandwidth) in the near I.R. region. The wavelength interval, 0.85 to 0.90 micron, was determined by a combination of I.R. film and an 87 C high pass filter. It can be seen that this bandwidth (0.85 to 0.90 micron) represents a very small fraction of the total available energy at any given temperature. The selection of a narrow bandwidth was dictated by good pyrometric practice which ideally suggests that monochromatic radiation be used. In the narrow bandwidth shown in figure 1, there is sufficient power radiated to permit the recording of temperatures as low as 1000° F. That is, with normal camera exposures and regular high speed infrared film, useable film densities were obtained.

In the near I.R. region, the emissivity for metals is generally higher and more stable than at the longer wavelengths. In addition, radiant emissions from combusted jet fuels have no interfering lines or significant band radiation in the 0.85- to 0.90-micron wavelength interval to cause errors in surface temperature measurements. Also, the bandwidth employed herein is in the general optical radiation band, which includes the ultra-violet, visible, and near I.R.; this permits the use of conventional optical techniques and photography. The emissivity of real targets (such as an unpolished nonblackbody surface) is essentially constant over a wide viewing angle. For practical systems, a conservative angle should be between 0° and 45° to the surface normal. Finally, the radiated energy in this wavelength interval varies rapidly with small changes in temperature thereby inherently providing high sensitivity.

Photographic System Description

The basic I.R. photographic pyrometry system illustrated schematically

in figure 2, consisted of the following four major components:

(1) A heated target which, in this example, was a symmetrical airfoil installed in a hot gas flow tunnel.

(2) An optical viewpath and a camera system, to uniformly transmit and image the target radiation from the heated surface to the I.R. sensitive film during a camera exposure.

(3) A film processing system, for the uniform development of the thermal images on the film strip.

(4) A densitometer, for measuring and recording the film density variation of a given thermal image and to automatically plot equal density contour maps of the film density distribution of the thermal image.

A thermal image of the heated target was formed on I.R. sensitive film by a remotely operated conventional camera system. The film strip, was developed and evaluated with a densitometer. The final data were presented as two-dimensional contour maps of temperature. The same system can be used for rotating blade surfaces by incorporating an Image Converter Tube (ICT) ahead of the camera. The ICT would act as a high speed shutter to "stop" the motion of the blade. However, other problems are involved which make the technique more difficult compared to stationary vane applications.

The system included a single exposure of a calibrated relative energy scale (step tablet or grey scale) on each film strip. This one exposure accurately determined the film response curve for all images on the balance of the uniformly processed film strip. With a single reference temperature for each thermal image, the film response curve was correlated to a temperature distribution curve. This latter calculated curve shows the distribution of temperature with relative radiant energy. A cross plot of the two curves (the film response curve, and the master temperature distribution curve) provides a calibration of film density distribution to surface temperature distribution. The reference temperature calibration point for this application was provided by a single thermocouple on the photographed surface of the target. The calibration procedure is detailed in reference 1. After processing, the film was evaluated with a densitometer which incorporated an automatic plotter of equal film density contours. The density contours were assigned temperatures from the calibration curve.

Application and Planned Improvements

I.R. photography has been applied to several test rigs including a static cascade with three viewports. Three camera systems were used. Each camera system included large capacity film cassettes, a motorized base, and an exposure control box containing a neutral density filter wheel. Selections of the filter, tripping the shutter and advancing the film was done remotely from the control room. The three cameras systems operated simultaneously. The application of I.R. Photography to the static cascade was generally successful and is presently in use. However, the field of view was limited through the existing viewports. Other application on rigs without this limitation were very successful. Even

with this limitation, the test program permitted us to develop hardware, improve our method and procedures, and gain valuable experience for future use.

The use of I.R. photography for temperature measurements in several test rigs of the near future will require some developmental effort. The basic technique previously described relied on large direct viewpaths and a direct calibration method that required a thermocouple in each camera field of view. An extension of the basic technique will involve the use of indirect viewpaths and indirect calibration methods. In addition, rapid film evaluation will be required for faster data reduction. Each of these areas is currently being investigated.

Indirect Viewpaths:

These viewpaths are optical transfer systems which can relay the radiation from the target to the camera lens in a uniform manner. Borescopes and fiber-scopes are being investigated. Such optical transfer systems allow relatively small penetration into hostile environments with a minimum perturbation to gas flow. They require cooling, and window flushing, to preserve physical integrity and window darkening, respectfully. Some problems (not encountered with direct viewports) are introduced when using borescopes and fiberscopes which make the method more complex. Some are: optical distortion, variable magnification with object distance, loss of image quality and radiant flux due to the small diameter of the optics. All of these areas will be investigated. The loss of flux can be recovered by adding an "image intensifier" in front of the camera lens. This device adds another degree of complexity which must be investigated. The coupling of these components (borescopes, image intensifiers, and camera) must be developed to insure optimum transfer. And the interfacing of the system hardware to the cameras and test rigs must be engineered. An application of indirect viewpaths is currently being planned. A single vane cascade will be equipped with borescopes as shown in figure 3. Four borescopes will be required to obtain full vane area coverage. Three will be located within replaceable side wall sections (two viewing the suction side, one viewing the pressure side of the airfoil) and one will be upstream approximately 5 inches. Each borescope will be contained in a cooling-flushing assembly and will be actuated into position only when a measurement is required. The borescope outputs will be optically coupled to remotely operated film cameras.

Indirect Calibration Techniques:

This area is concerned with developing methods which can provide a single reliable reference temperature. All other temperatures depend on this one measurement. These techniques must consider the basic radiation heat transfer process which include target characteristics and hot gas stream effects such as luminosity, reflection, viewing angle and viewport transmission factor. The film density is a precise measurement of the exposure energy. However, the reduced exposure energy can vary drastically from the actual radiated energy

from the target. Many factors effect this reduction in intensity. It is virtually impossible to accurately correlate the ratio of radiated surface energy to film exposure energy. This is why a reference thermocouple is used whenever possible. However, since thermocouples can fail, or may be impractical to install in some structures, it is becoming increasingly important to develop reliable indirect calibration techniques. Indirect techniques will require more control and will be inherently less accurate than the direct thermocouple technique. Development in this area will be concerned with screening the various possible methods to determine the one most suitable for our applications.

Rapid Data Analysis:

It is essential to reduce the film data rapidly by using a fast scanning microdensitometer. This instrument will reduce the time to obtain an isodensity plot to about ten minutes and is 10X faster than the previous method. Secondly, the fast scanner is capable of digitizing the density information so that it can be computer processed. Much effort remains to be done to accomplish this aspect of faster data analysis. Eventually we hope to instantaneously identify the temperature of each contour. An example of a hard copy of isodensity plot by the rapid film scanner is shown in figure 4. The plot was made as a 10X enlargement during the time of the scan. In addition to quantizing the film image into density increments the scanner also preserves the continuous tone background for qualitative identification of hotter areas.

Electro-Optical Systems

The photographic method described in the previous section points up the kind of basic information and procedure that is required for making temperature distribution measurements. But this method provides "post mortum" information. Often, temperature information is required during the real time of the test. Such information can shorten testing time (thereby reducing operating costs) by permitting the experimenter to quickly screen vane and blade cooling effectiveness on a qualitative basis and then concentrate on tests that are feasible, and where thorough data analysis would be desirable.

Electro-optical imaging systems appear to be practical for such application. Such systems can scan the object plane or an image plane in real time and form an electronic image. An electronic image can be digitized and computer processed, using the same kind of calibration information required for the photographic method, but in a much faster time. In addition, the film processing procedure is entirely eliminated. Some components of such electro optical systems exist today in the form of thermal image scanners. But these commercial systems do not use detectors that operate in the spectral region of approximately 1.0 micron, the region so useful for turbine cooling application for the reasons stated previously. One potential detector is the silicon diode array (imaging) vidicon tube. Here a hot target can be imaged onto an array of tiny silicon detectors. The detectors (resolution elements) are then electronically scanned (like a TV

transmitting tube). The output signals can be digitized to represent discrete
intensity levels for each corresponding resolution element on the target surface
which in turn can be calibrated into temperature and presented in a variety of
forms by the computer. This approach will be investigated so that the photographic
method can be supplemented or perhaps entirely replaced. Such systems seem
readily adaptable to rotating blades as well as stationary vane targets. Other
developments, using silicon detectors, are already in progress.

Multi-Spot Blade Scanner

One type of electro-optical system under development at the Lewis Research
Center uses a linear array of fiber optics, a mechanical scanner, and a silicon
avalanche detector. The system is being designed for use in a test engine to
measure the temperature along 80 scan lines across the surface of a rotating
turbine blade, as shown in figure 5.

The fiber optic probe will be contained in an assembly which will provide
water cooling and lens air flushing. The assembly will be inserted into the
engine by an actuator when a measurement is required. A single lens focuses
radiation from 80 adjacent spots on the blade to an array of 80 optical fibers
within the probes. The fibers transfer the radiation out of the engine to a
remote scanner and signal processor. In the scanner, the fibers are physically
separated, and their outputs scanned and measured in sequence. The details
of the scanner system, the blade sync system and the signal processing are
discussed in reference 2. The system can be used with rotating blades or
stationary vanes. In the latter case, a rotating mirror will replace the blade
motion.

Single-Spot Measurements

Other less involved electro-optical systems are also in use at Lewis. These
are for the most part commercially available radiation thermometers which use
detectors having a spectral response in the 2.0 - 2.5 micron region. The units
(the size of a home movie camera) are used where spot measurement are adequate.
They have also been adapted to scanning platforms which presently scan in one
direction only and record a line scan.

Small spot miniature radiometers similar to the ones available from several
instrument manufacturers and aircraft companies are being investigated. These
units have been engineered specifically for surviving the adverse environment
of a jet engine. Much effort has been made to reduce the measured spot size,
keeping the optical probe head clear and cool, and develop sophisticated signal
processing. There are several Lewis rig applications in the near future that
will require such systems.

ROTATING MEASUREMENT SYSTEMS

Another area of instrumentation research concerns rotating measurement systems. Two such systems were developed at the Lewis Research Center. One system for pressure measurement and the other for temperature (thermocouple) measurements. The two separate systems were simultaneously developed and are the combined efforts of several groups within the Lewis Research Center. Each system was designed to operate at speeds up to 9000 rpm in temperature environments of 275 to 340 K (35° to 150° F). Each system consisted of a rotary package and stationary instrumentation. Each rotary package was approximately 17 centimeters (7 in.) diameter and 37 centimeters (15 in.) long. Either system could be mounted separately on an engine or in tandem.

Figure 6 illustrates schematically the location of the rotary packages (mounted in tandem) on a test engine. Pressure tubing extending from the sensing ports in the turbine section terminate in the Rotary Pressure Package after passing through the hollow shafts in the engine. Thermocouples from the rotating turbine components pass through the same hollow shafting and terminate in the rotary package of the Shaft Data System

Rotary Pressure Measurements

System Description

A ten-channel rotating pressure measuring system (ref. 3), was designed for obtaining steady-state pressure data from air-cooled turbine blades.

A photograph of the rotary package is shown in figure 7. It consisted of a stationary outer housing, a rotating bulkhead assembly containing the differential pressure transducers, calibration ports, pressure tubing inlet ports (not shown), and a slip ring assembly. The transducers were used to convert a pneumatic pressure force into an electrical signal. The slip ring assembly transferred excitation voltage from a stationary power supply to the rotating transducers. It also transferred output signals from the transducers to stationary signal amplifiers.

Variable Reluctance Transducers

The transducers selected for the rotary pressure package were the variable reluctance pressure difference type shown schematically in figure 8. This transducer was selected after a variety of commercially available pressure transducers were tested. Transducers were available in a variety of differential pressure ranges from 0 to 1.4 newtons per square centimeter (0 to 2 psi) to 0 to 70 newtons per square centimeter (0 to 100 psi). The overall size of the transducers was the same for all pressure difference ranges. The transducers

were 1.1 centimeter (7/16 in.) in diameter and 0.6 centimeter (1/4 in.) wide. The transducer consisted of two sturdy symmetrical case halves separated by a diaphragm. Both the case and the diaphragm were magnetically permeable material. Each case half was a circular cup core in cross section and contained an inlet pressure port on its centerline. An insulated inductance coil made of manganin wire was secured in each case half. An air gap existed between the cup core and the diaphragm.

System Description

Figure 9 is a block diagram of the ten-channel rotating pressure measuring system. Each transducer was excited by the common oscillator power supply of 5 volt, 20 kilohertz. Within each transducer the two coils were connected in series and formed two arms of a four-arm bridge circuit. The two other arms of the bridge circuit were internal to a stationary carrier amplifier. When a pressure difference was applied to the transducer, the diaphragm deflected thereby changing the magnetic reluctance coupling between the two case halves. This unbalance changed the inductance of the coils which was sensed by the bridge circuit. The signal was transferred electrically through slip rings to the stationary carrier amplifier and the data recording system.

The commercially available slip ring assembly provided a mercury wetted interface between each rotating ring and its associated stator ring. A pool of mercury within each ring compartment was centrifuged during rotation. This centrifuging produced a continuous contact around the periphery resulting in a noiseless electrical contact between the slip ring rotor and stator. The slip ring assembly contained thirteen signal transfer rings. Two rings carried the carrier oscillator power supply to the ten transducers. Ten rings were used to transfer the individual outputs of the transducers to individual stationary carrier amplifiers. The remaining ring was used as a common system ground link.

Mechanical Design

A cutaway drawing of part of the assembled rotary package is shown in figure 10. It shows the bulkhead assembly previously mentioned in figure 7 which consisted of transducer compartments, a mounting plate and a pressure tubing compartment. Each transducer was mounted in a separate transducer compartment so that the transducer diaphragm was in the plane of rotation. The transducer centers were separated from each other by 36 degrees and were mounted 2.86 centimeters (1.125 in.) off the shaft center line. The transducer compartments were easily removable from the bulkhead assembly for convenient installation or replacement of the transducers.

The transducer compartments were attached to one side of the mounting plate. The interfaces between the transducers and the mounting plate and compartments

were sealed with "O" rings. The clearances were adjusted so that the "O" rings were compressed properly to seal the pressure, yet no strain was placed on the transducer case. A strain on the transducer case can cause either a zero shift or a sensitivity change or both. Pressure calibrations were rechecked after the transducers were installed in the transducer compartments to verify proper installation.

Mated to the engine side of the mounting plate with five bolts, was the pressure tubing compartment. This compartment contained ten pairs of inlet ports, one pair for each transducer. The pressure tubes extending from pressure measuring points in the test engine terminated at these ports. The inlet ports had tapped holes for compression fittings. The pressure tubing inlet ports were connected to the transducers by means of a series of mating drilled passages through the bulkhead assembly as shown in the figure. Pilot tubes were inserted in the drilled passages on the mounting plate; around each pilot tube was an "O" ring to seal the pressure transfer junction. The mounting plate had a stub shaft that was used to couple it to the slip ring assembly shaft by means of spines and a collet nut.

In addition to the details described above, several important features of the rotary package are worth noting. The rotary package was designed to mount externally on an engine and rotate with the engine shaft. The bulkhead assembly (mounting plate, transducer compartments and pressure tubing compartment) was massive to ensure rigidity and temperature stability for the transducer. A hollow shaft was provided throughout the package thus allowing thermocouple leads to extend from the engine, through the shaft of the rotary pressure package and to a rotating thermocouple slip ring device or a shaft data system mounted in tandem with the package. Finally, each transducer could be calibrated at nonrotating conditions after the package was assembled by using the calibration ports provided in the pressure tubing compartment.

The rotary pressure measuring system was spin tested to speeds of 9000 rpm. Stationary tests indicated a system error within 1 percent. Rotary tests indicated a system error within 3 percent at maximum rpm. The performance of the transducer channels was affected by centrifugal force. A simple screening method was used to evaluate the system under rotating conditions. Complete details of the system and the spin tests are presented in reference 3. The rotary package is now being adapted to measure rotating blade airflow quantities on a spin rig before engine application.

Rotary Thermocouple Measurements

System Description

Temperature measurements are also being made with thermocouples secured on rotating turbine components. The 72-channel rotating shaft data system (refs. 4 and 5) was developed to replace slip ring assemblies. This electronic

system can transfer steady-state thermocouple data from rotating turbine components to stationary read-out equipment.

A cutaway drawing of the rotary package of the shaft data system is shown in figure 11. The package consisted of a stationary slotted housing, a two-winding rotary transformer, and a rotating framework containing the data system electronic assembly and the thermocouple terminal ring. The stationary housing was designed to attach to the front end of the test engine casing in the same manner as the rotary pressure package discussed previously (see fig. 6). A circular support collar was provided to support the opposite end of the housing. The rotary transformer was also attached to this end and was used to transfer power into the electronic assembly and to transfer thermocouple data from the electronic assembly. The rotating framework was mounted between end bearings within the housing and was mechanically coupled to the engine shaft on one end and the transformer rotor shaft on the other end. Thermocouples from the engine turbine components entered the package through the hollow shaft and were soldered to posts on the 144 position terminal ring. The terminal ring serves as a cold junction for the thermocouples, and its temperature is monitored by a thermistor. The electronic assembly and the terminal ring are mounted to the rotating frame-work with three tie rods. A metal spacer plate was used for alignment so that slight irregularities in the circuit boards (compressing the electronic assembly) would not affect the mechanical mounting. Connections from the rotary trans-former to the electronic assembly are made through the hollow shaft to another terminal ring. Both terminal rings are accessible through the slotted stationary housing making it possible to connect the data system in a minimum of time. The housing shown in the figure is considerably larger than necessary to properly support the electronics. Its dimensions were determined by the practical require-ment that the package be identical in length to the assembly (slip ring) which it replaces.

Data System Electronic Assembly

The data system electronic assembly shown in figure 12 was assembled by stacking the circuit boards together with spacers and making the required inter-connections. Double-sided printed circuit boards with plated through holes were used. The five board assembly was about 9 centimeters (3.5 in.) diameter by 6 centimeters (2.5 in.) long. Commercially available integrated circuits were used whenever possible. Components most sensitive to acceleration were mounted near the center of the boards. Interboard connections were made near the periphery of the boards to facilitate testing the assembled system. The assembled boards were coated with a clear epoxy to hold the components securely to the boards.

System Description

A block diagram of the rotating shaft data system is shown in figure 13. One winding of the rotary transformer, is used to couple 10 kilohertz power onto

the shaft mounted electronic assembly. Another winding is used to transfer the output signals in the form of a digital serial train from the electronic assembly to a signal processor and readout instrumentation. The operation of the rotary transformer does not rely on rotation, nor is the performance affected by rotation. The electronic assembly incorporates circuits for multiplexing, amplifying, and digitizing the thermocouple signals. In addition, it contains a power converter required to supply the necessary DC voltages for the operation of the above-mentioned circuits. Briefly, the multiplexer acts like a 2 pole-72 position switch. The continuous switching is done at a rate of 156 data channels per second. This multiplexing of input signals (thermocouples) is an efficient method of processing large numbers of data channels, since only one signal path is then necessary through the amplification and digital conversion functions of the system. The digitized signal outputs are in the form of 8 bit binary words, and leave the data system, through the rotary transformer as a pulse code serial train. In practice, three of the 72 data channels are used for calibration signals to monitor the performance of the data system. In addition, one channel measures the temperature of the thermocouple terminal ring and is used as the thermocouple cold junction reference temperature. The output from the rotary transformer is fed to a digital signal processing unit which converts it into a form compatible with the central data processor at the Lewis Research Center. In addition, this output information is displayed on a 72-channel digital bargraph scope which is coupled to a printer. A printed copy of the information is available on command.

The rotary shaft data system was tested up to speeds of 9000 rpm. The system error under these conditions was demonstrated to be within one count of 256. This corresponds to a temperature error of about 5 K (10° F) at 1150 K (1600° F) temperature level. Figure 14 shows the system as it is presently mounted on a test engine in tandem with a conventional slip ring assembly. Twelve thermocouples are common to both systems for comparison checks. The test engine contains both slave and test blades instrumented with Chromel Alumel (CA) thermocouples. Figure 15 illustrates a typical digital bargraph display during a test run.

CONCLUDING REMARKS

Instrumentation development and application in the areas of surface temperature mapping on stationary vanes and rotating blades at steady-state conditions will continue to be explored with imaging techniques. The problems common to both photographic and electronic imaging in the near I.R. region will continue to be investigated. Some areas under consideration are: optical transfer systems, temperature calibration techniques and computerized data reduction. The research effort is a continuing one, requiring frequent updating because of rapid advances in the field of I.R. technology and electro-optics in the military and civilian communities. These advances can be applied to the fields of thermography and radiation pyrometry for turbine cooling applications.

Rotating measuring systems will be thoroughly tested and modified in order

to improve accuracy and reliability. Such systems are required for making pressure measurements on rotating blades and for transferring large numbers of electrical signals from rotating turbines. An advanced system development, which will combine pressure transducers and thermocouple signals with a shaft data system, is planned. Such a system will be required to rotate at speeds up to 18 000 rpm.

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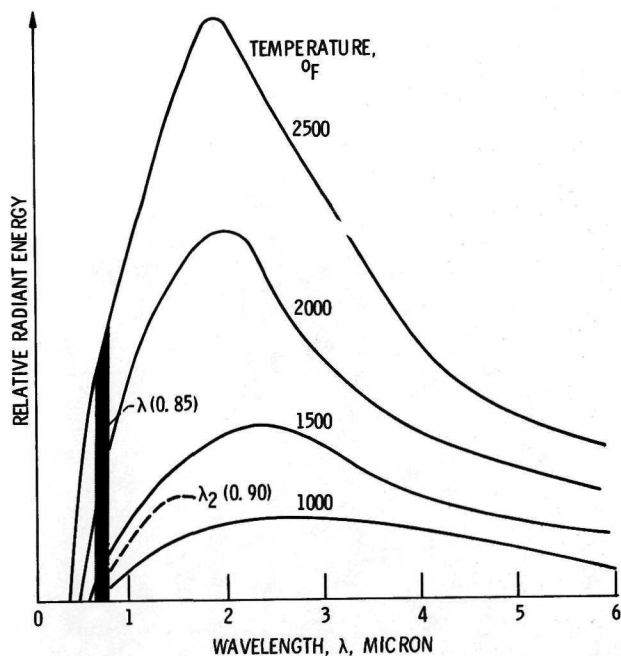
Figure 1. - Typical blackbody spectral energy distribution for various temperatures.
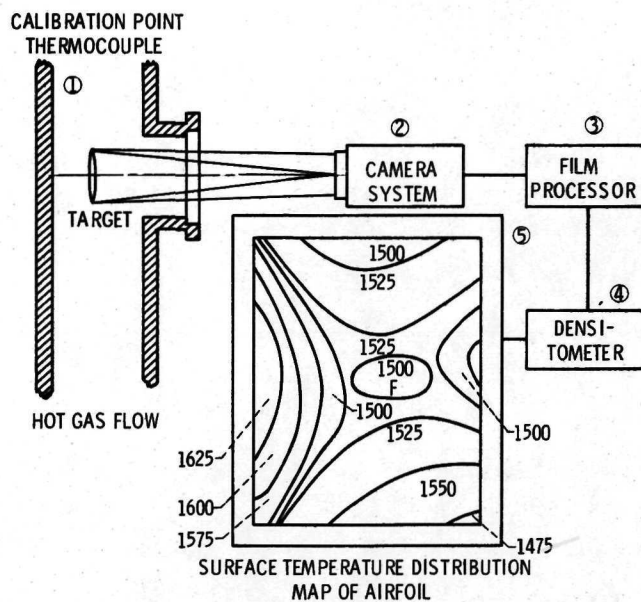
Figure 2. - IR Photographic pyrometry system.
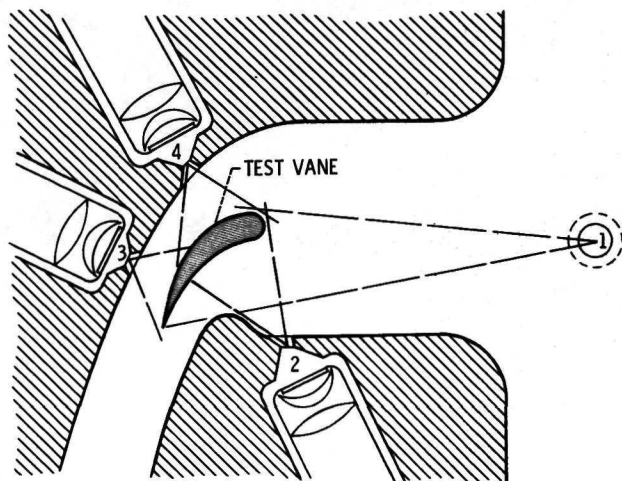
Figure 3. - Borescope layout for single vane cascade.
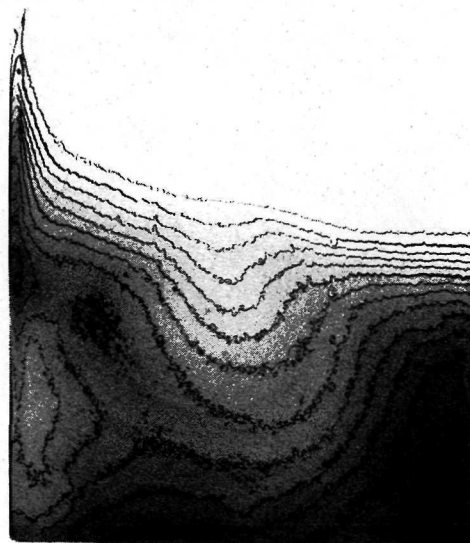
Figure 4. - Isotherm plot of a thermal image.
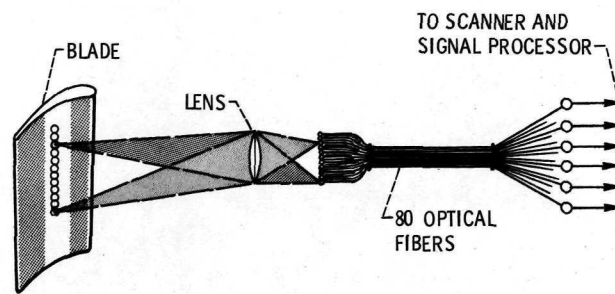
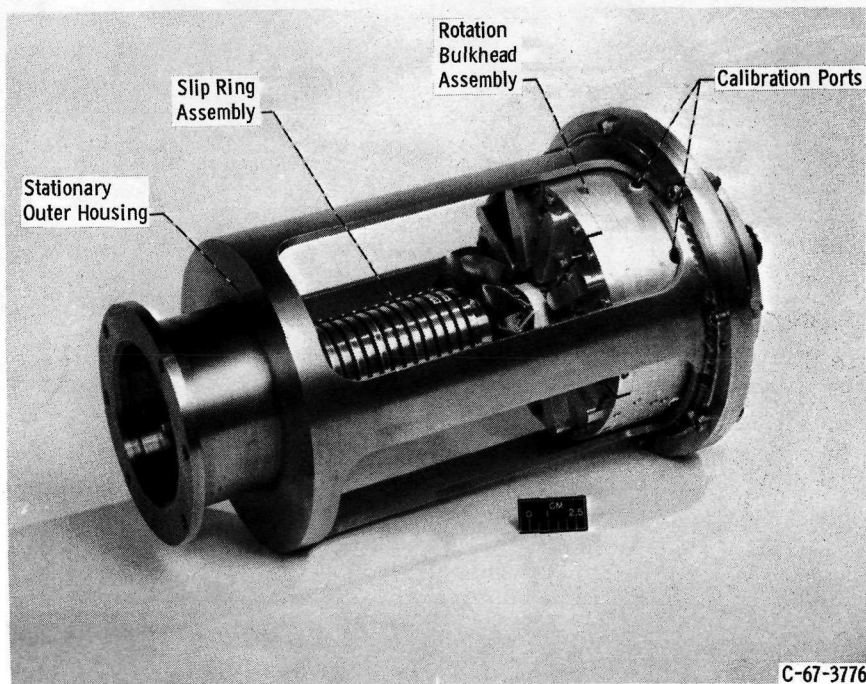Figure 5. - Multi-spot blade scanner
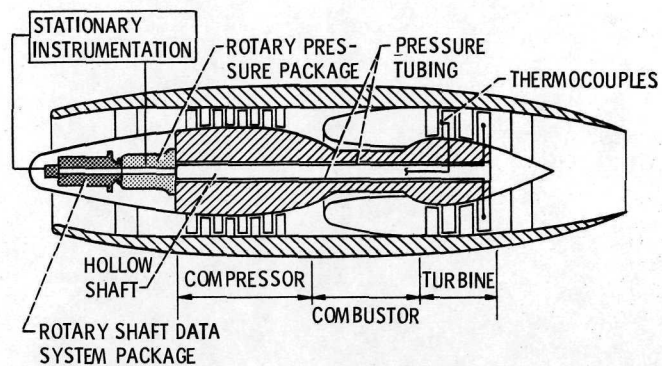
Figure 6. - Engine-rotating measurement systems configuration.

Figure 7. - Rotary pressure package.

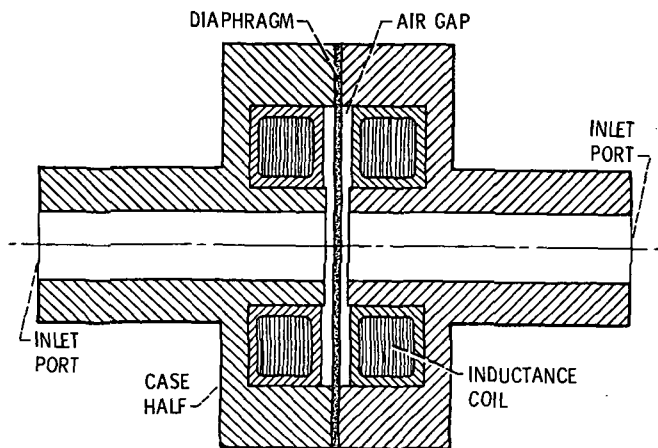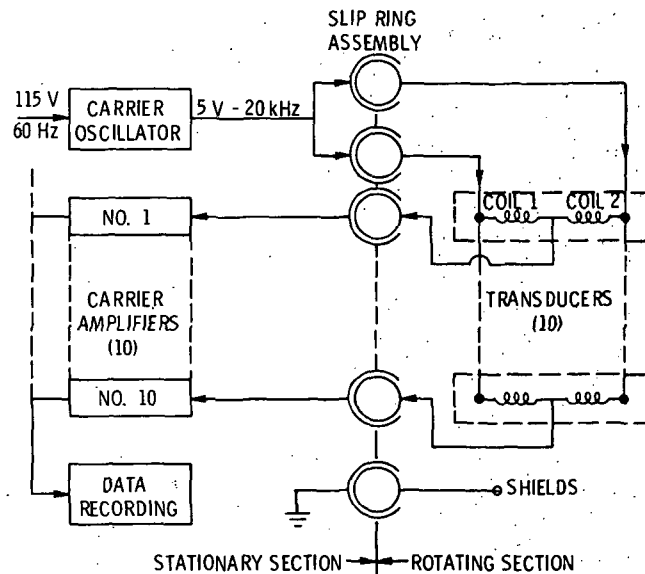Figure 8. – Variable reluctance differential pressure transducer.

Figure 9. – Block diagram of 10 channel rotating pressure measuring system.
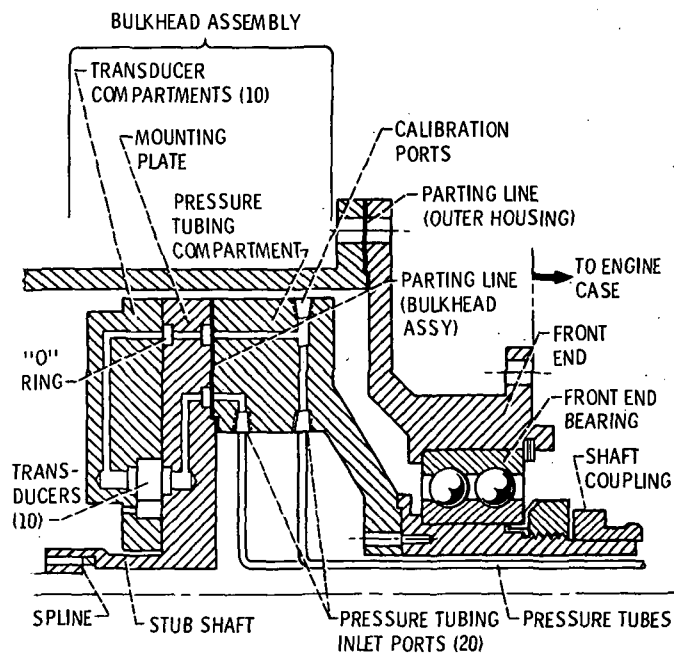
Figure 10. – Cutaway drawing of the rotary pressure package.
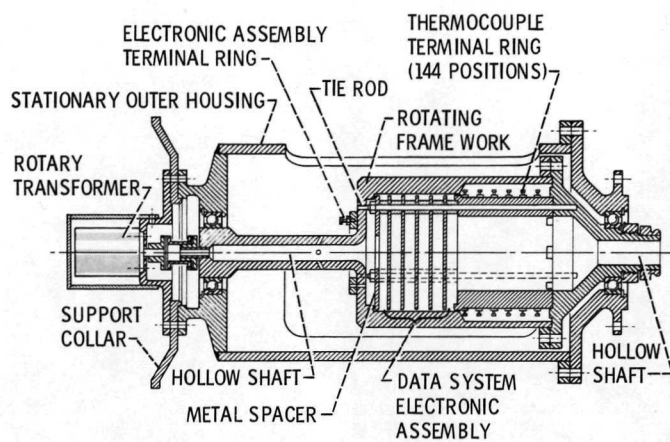
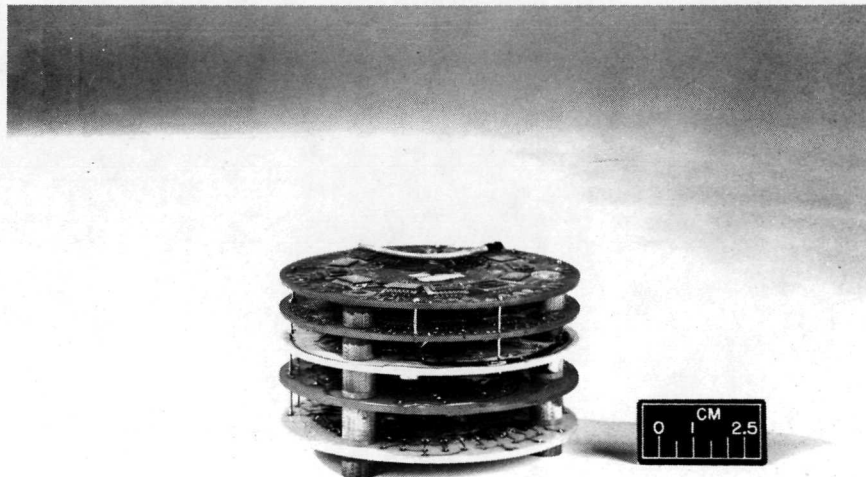Figure 11. – Cutaway drawing of the rotating shaft data system.
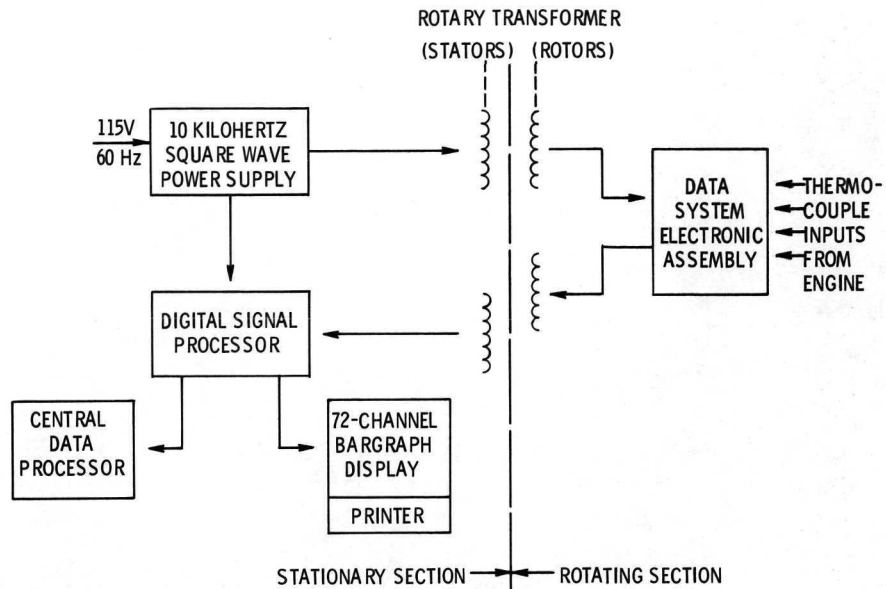

C-69-1835

Figure 12. – Shaft data system electronic assembly.

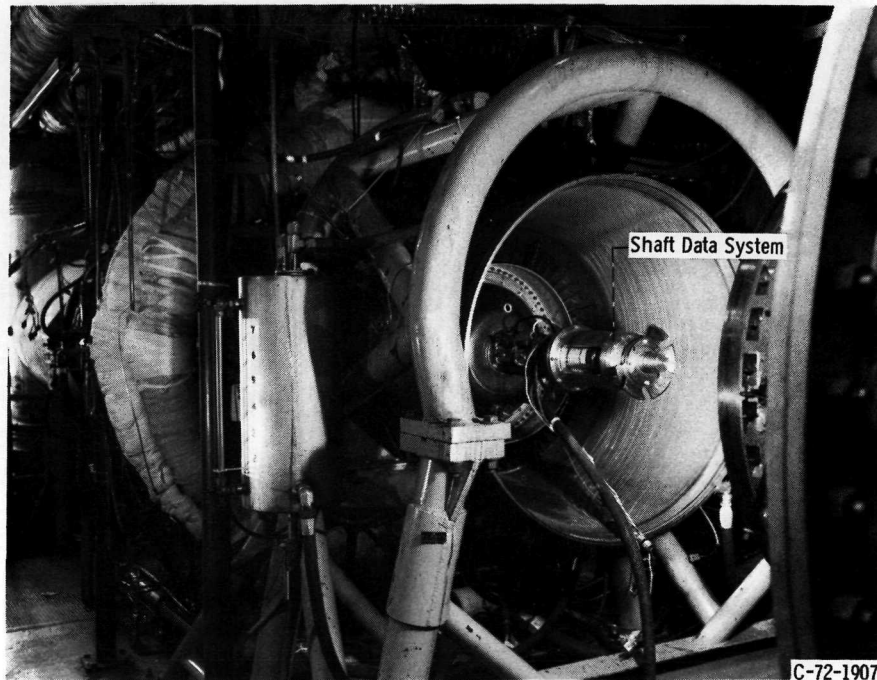Figure 13. – Block Diagram of the Rotating Shaft Data System.

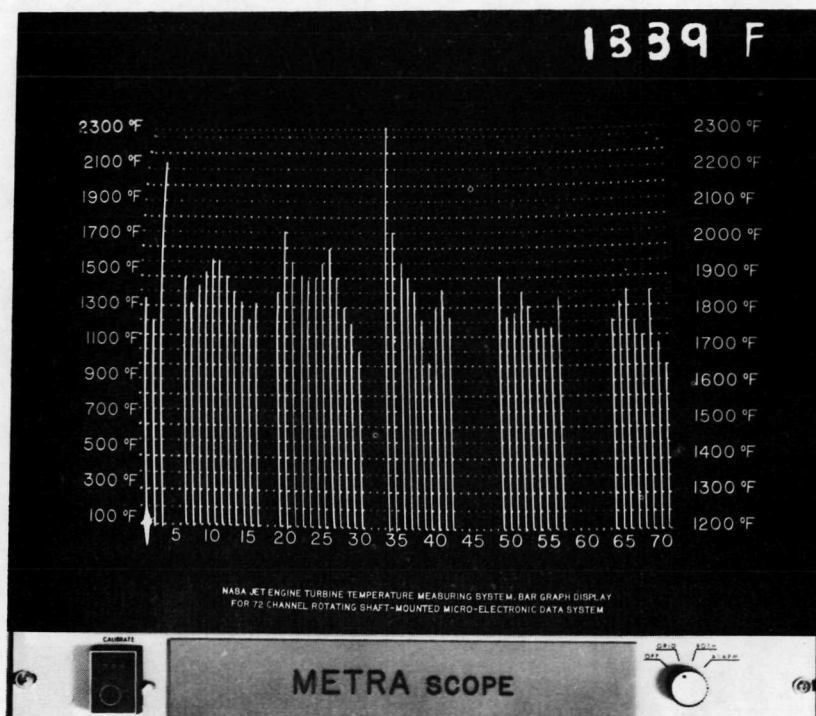Figure 14. – Shaft data system mounted on test engine.

Figure 15. – Temperature display on 72 channel bargraph scope.

C-72-2414